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Quarterly Technical Summary

Air Traffic Control

15 November 1971

Prepared under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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INTRODUCTION

This report describes the research activities during the August-October 1971 period in Air Traffic Control which are funded by the Air Force. Where these activities are related to work supported by other agencies, this interrelationship has been noted.

Progress on other ATC tasks during this quarter included the release by the FAA of the Technical Development Plan for the Discrete Address Beacon System which was formulated with Laboratory support, the initiation of a program for the FAA to develop improvements in the ATC Surveillance System, and the beginning of an additional program for the FAA in Interactive Graphics.

H. G. Weiss
Head, Division 4

15 November 1971

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

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AIR TRAFFIC CONTROL

I. SUMMARY

The Air Traffic Control Program at Lincoln Laboratory was initiated by the Air Force about two years ago with the concurrence of the FAA because, as a major user of the ATC system, it was appropriate to explore the application of technology developed for the military to this important national system. Within the past six months, the majority of our effort has shifted to specific tasks for the FAA. Only that portion of our ATC work which continues under Air Force support is reported herein.

Investigations in the general area of surveillance technology include further study of a new theory to upgrade the angle estimation accuracy of radar and beacon systems utilizing phase monopulse, an expanded program to test current ATC Radar Beacon System (ATCRBS) Transponders, and additional work directed toward significant improvements in the MTI performance of radar. Progress in these studies is reported in Sec. II.

Work is continuing on the systems engineering and simulation studies of an Airborne Traffic Situation Display which will provide pilots with an integrated air traffic and navigation capability. In addition, a cost-benefit study of an Airborne Traffic Situation Display operating as an adjunct to the advanced Third Generation ATC System was initiated for the Aviation Advisory Commission. This work is described in Sec. III.

Effort in our program to develop a plan for acquiring detailed data on propagation effects required for the design of a Communications, Navigation, and Identification System (CNI) is concentrated upon developing a first-order model suitable for quantitative predictions of propagation parameters caused by ground reflection. This study is reported in Sec. IV.

In our study of Microwave Landing Guidance Systems reported in Sec. V, emphasis was placed on defining areas requiring expanded research and development.

II. SURVEILLANCE TECHNOLOGY

During the past quarter, the Technical Development Plan for a Discrete Address Beacon System (DABS) was released by the Federal Aviation Administration (FAA). The Laboratory worked closely with FAA agencies in the preparation of this plan. Concurrently, our investigation of ATCRBS transponders was expanded, and our studies of monopulse techniques for radar and beacon systems as well as MTI radar processing have continued.

Close coordination has been maintained with the work of the Radar Group and the Digital Signal Processing Group on a high-resolution electronically scanned radar system which is now radiating and being debugged. We are evaluating the use of this system as a radar test bed for all-weather, clutter-free monitoring of air traffic.

A. ATC Radar Beacon System Development

1. Angle Estimation Accuracy for Phase Monopulse Systems

The theory has been refined for the angle estimation accuracy of phase monopulse beacon and radar systems (with sum-and-difference signal processing). Such a system is under consideration for application in upgraded ATCRBS and DABS for target azimuth determination. The

results of the theory are given in closed form and apply at on- and off-boresight angles for an arbitrarily nonlinear angle offset (or error) curve. The theory is derived for a general class of commonly used equipment and should yield more realistic results than that given by maximum likelihood estimation theory. The theory takes into account both the sky and receiver noise and the correlation between the possibly unequal components of these in the two channels feeding the angle detection circuitry. It also accounts for any particular antenna patterns which may be applicable. Apart from the quantitative results, an interesting qualitative observation is that at, or near, boresight, the rms angular deviation from the mean is inversely proportional to the ratio of the signal in the sum channel to the noise in the difference channel. The identical observation was made in the previous Quarterly Technical Summary for amplitude monopulse systems. Numerical studies are planned for the next quarter for a variety of antenna patterns and system parameters.

2. Transponder Test Program

The program of field measurement initiated with Air Force support to obtain the operating characteristics of ATCRBS transponders continued during this quarter for the FAA. Following a review of the data obtained from the initial test of 96 aircraft, the FAA requested that the program be continued through the testing of 500 transponders. Tests are now being conducted in the New York-Connecticut area.

B. MTI Studies

In the last Quarterly Technical Summary, it was shown that optimal signal processing could lead to significant improvements in MTI performance. Furthermore, a processor that achieves essentially optimum performance is straightforward to implement by using digital signal processing techniques. In order to determine whether or not these gains can be achieved at reasonable cost, a real-time experiment has been proposed. In anticipation of some of the problems that might arise in the execution of this experiment, a computer simulation of the signal processing functions has been undertaken and is nearing completion. It is possible that the design of the radar modifications and the receiver A/D conversion equipment will be specified during the next quarter.

III. AIRBORNE TRAFFIC SITUATION DISPLAY

A concept for an airborne traffic situation display system is under investigation which would provide pilots with a CRT display of adjacent air traffic labeled with identification, altitude, and ground speed. It could also present relevant map data, including navigation fixes, airways, obstructions, and weather contours. In concept, the data for this display would be transmitted over a narrowband data link from the ground-based NAS/ARTS equipment now being widely installed by the FAA.

A. Design Studies

During this quarter, the design of the display hardware was completed and prototypes of all modules except for the computer interface and character generator were tested. Checkout of the entire system with the exception of the character generator is scheduled for early in the next quarter. The character generator will be tested when its memory is delivered during the quarter.

Software for a demonstrative program and a display testing program are being assembled.

B. Display Simulation*

Display simulation studies on the M.I.T. campus are continuing under the sponsorship of the FAA.

C. Cost Benefit Analysis

This study, initiated on 1 July under the sponsorship of the Aviation Advisory Commission, is assessing the utility of the ATSD as an adjunct to the Upgraded Third Generation ATC system planned by the FAA.

IV. COMMUNICATIONS, NAVIGATION, AND IDENTIFICATION SYSTEM

Under the sponsorship of the Electronic Systems Division, a study is under way to understand in detail the impact of propagation phenomena on the choice of a modulation scheme for use in CNI systems. A variety of links, including air-to-air and air-to-ground, will be investigated along with the combination of operating modes and propagation effects.

The basic propagation phenomena can be conveniently catalogued in three broad classes. These are: surface-reflected multipath, atmospherically caused effects, and aircraft-produced effects (e.g., multipath encountered with large airframes can have differential delay times on the order of 10 to 250 nsec).

Our current efforts are directed at obtaining a first-order model suitable for quantitative predictions of propagation parameters caused by ground reflection. The field scattered from rough surfaces has traditionally been decomposed into two components: specular and diffuse. The specular component results from reflection from the Fresnel ellipse, is coherent, obeys classical laws of optics, and has a non-random amplitude. The diffuse component is due to reflection from the glistening surface (an area larger than the first Fresnel zone), is incoherent, has little directivity, and has a random amplitude.

A mathematical model has been obtained which is suitable for first-order estimates of the time-delay difference between the direct and specular reflection and the time spread of the diffuse reflection. We detail a few of the results obtained from this model.

The estimate of the boundaries of the glistening surface in our analysis is based on the following assumptions.

(a) The surface of the earth is rough; the heights of its peaks are normally distributed with standard deviation σ.

(b) The horizontal autocorrelation function, R(d), is identical for all directions and is assumed of the form $R(d) = \sigma^2 \exp[-(d/d_o)^2]$, where d is the distance and d_o is a constant.

(c) The rms height of the irregularities, σ, is large compared with the space wavelength $\lambda/\sin\gamma$, where γ is the grazing angle and λ is the wavelength, e.g., one foot at L-band.

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* Collaborative laboratories on the M.I.T. campus:

Flight Transportation Laboratory, Aeronautics and Astronautics Department
Electronic Systems Laboratory, Electrical Engineering Department
Man-Vehicle Control Laboratory, Aeronautics and Astronautics Department

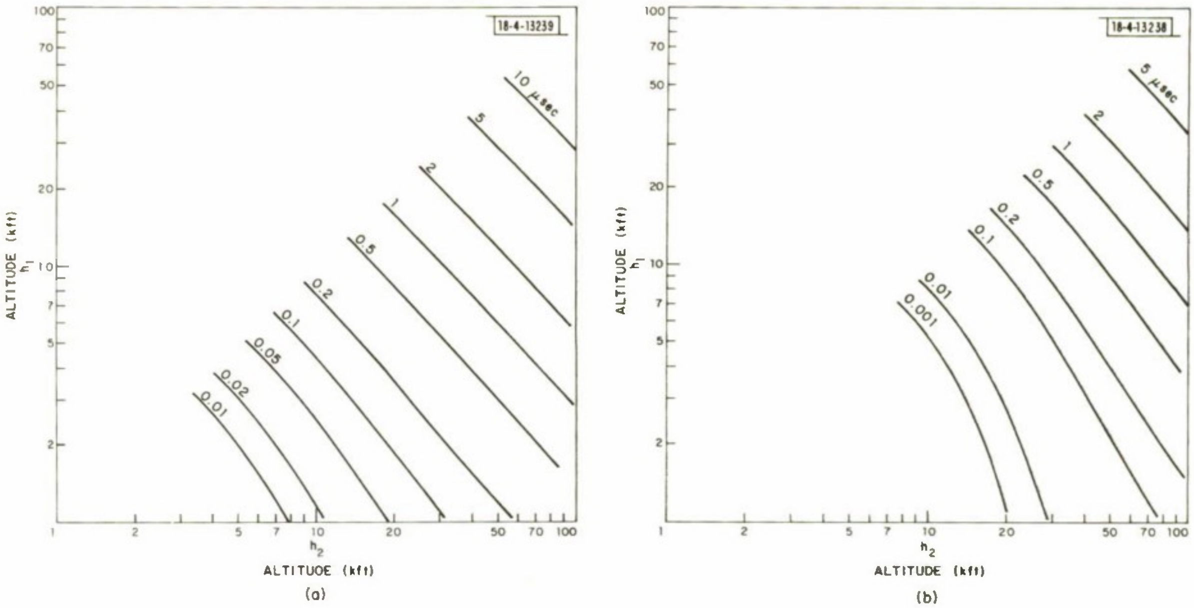

Fig. 1. Locus of aircraft altitudes and indicated differential delays between specular and direct rays: (a) 100-mile separation; (b) 200-mile separation.

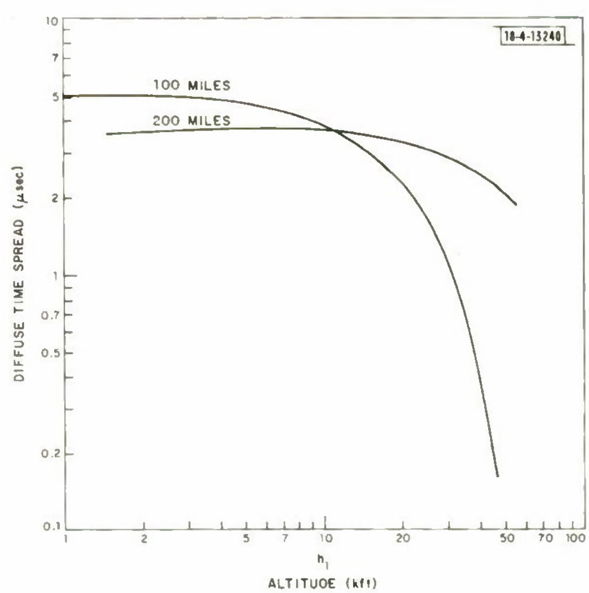

Fig. 2. Maximum diffuse time spread for an aircraft altitude $h_2 < 60{,}000$ feet and $\beta_a = 0.1$.

(d) The heights of the transmitting and receiving antennas are small compared with the distance between them.

(e) Both transmitting and receiving antennas view the entire glistening surface.

Based on the above assumptions, the glistening surface is found to be a function of the geometry of the transmitter and receiver antennas and the parameter β_o, where $\tan\beta_o = 2\sigma/d_o$.

For a given geometry and β_o, the time spread of the diffuse scatter was determined by comparing the time delay of a wave reflected from the specular point (shortest path) to a wave reflected from the boundary of the glistening surface.

We summarize results for $\beta_o = 0.1$, which is representative of rough sea conditions. In Figs. 1(a) and 1(b), we present the locus of aircraft altitudes, h_1 and h_2, which results in the specified differential delays between the direct and specular paths for aircraft separations of 100 and 200 miles, respectively. In Fig. 2, the maximum time spread of the diffuse return is plotted for $h_2 < 60{,}000$ feet. It is interesting to observe that the time spread in the diffuse return can be larger than the differential delay between the direct and specular rays.

V. MICROWAVE LANDING GUIDANCE SYSTEMS

Study is continuing on microwave landing guidance systems, with emphasis on defining high impact areas for an expanded research and development activity. Some of the key areas identified to date are described below.

(a) Meaningful characterization of environmental effects such as multipath, rain/snow alternation, and refraction. Such environmental effects on system performance may well be the key technical factor in choosing between alternative systems as well as in assessing the usefulness of the microwave systems in providing landing system guidance. In this area, the initial effort consists of obtaining an in-depth understanding of each of the potentially important effects and the design of a follow-on experimental program to measure the critical parameters.

The objective of the above efforts will be to develop a detailed understanding of the environmental effects so that landing system performance degradation can be predicted for a variety of system configurations as opposed to determining only the extent to which one specific configuration is degraded. Some important advantages of the approach outlined here are:

(1) It provides a meaningful input to microwave landing system performance optimization studies.

(2) The results are of use in assessing the performance degradation of alternative landing systems such as PAR/GCA.

(b) Evaluation of the ability of particular techniques to meet the system requirements. The topics studied in such an evaluation would include:

(1) Assessment of the fundamental limitations on angle estimation accuracy attainable with the scanning beam and Doppler LGS concepts, including a consideration of the important parameter variations within each technique (e.g., the means of providing angle reference information in scanning beams).

(2) Evaluation of the effects of multipath and other propagation anomalies on the accuracy and reliability of both LGS concepts.

(3) Determining the complexity of the signal processing required to realize the desired performance.

(c) Consideration of alternative system configurations. The Radio Technical Commission for Aeronautics (RTCA) Special Committee SC-117 has proposed a microwave landing system with C-band measurement of azimuth and elevation angles and distance, and with K_u-band elevation guidance element for installations that provide flare guidance to touchdown. For military use, it may be desirable from the viewpoint of ground antenna size to have all guidance information provided at K_u-band, provided that the operational requirements can be met. The results of the environmental effects and techniques evaluation studies could be used to assess the feasibility of alternative configurations such as:

(1) An all K_u-band system,

(2) TACAN (to provide terminal area guidance information) combined with an all K_u-band system (to provide near touchdown guidance).

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13. ABSTRACT

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14. KEY WORDS

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digital signal processing
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Air Traffic Control Radar Beacon System (ATCRBS)
Communications, Navigation, and Identification System (CNI)
Microwave Landing Guidance Systems